Accurate Representation of Arbitrary Depth Source Terms in Coastal Wave Prediction Models

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LONG-TERM GOALS

The principal goal of this project is to improve our understanding of the interactions governing the spatial and temporal evolution of surface waves in arbitrary depths. This will be accomplished through the Shoaling Waves large-scale field experiment (SHOWEX) and coordinated wave modeling improvements through the Advanced Wave Prediction Program (AWPP). The results of these studies will fill Naval Operational wave forecasting needs for accurate and computationally efficient estimates of the nonlinear wave-wave interaction (S_{nl}) source term for arbitrary depths.

SCIENTIFIC OBJECTIVES

The principal objective of this project is to investigate via numerical means the source term balance in shoaling waves, test newly constructed exact S_{nl} solutions, develop an improved Discrete Interaction Approximation (DIA, Hasselmann et al 1985, Komen et al 1994), test the approximation method, and ultimately implement this approximation in existing Naval Operational Wave Forecasting methodologies.

APPROACH

The action balance equation has two distinct parts to be solved: spatial changes in the spectrum (i.e. propagation shoaling and refraction) and the temporal changes described by the source terms: atmospheric input (S_{in}), nonlinear wave-wave interaction (S_{nl}), dissipation due to whitecapping (S_{ds}), and wave-bottom effects (S_{wb}). The Shoaling Waves field experiment (SHOWEX) will attempt to directly measure the atmospheric input, whitecapping, and the effects of wave-bottom interactions. The nonlinear interactions will be directly calculated in this study using the work of Resio et al (accepted for publication, *JGR*) for arbitrary depths. Assessment of the dissipation measurements will be indirectly validated from the source term balance, (again computed from all mechanisms). Exact solutions (using the full dispersion relationship) as well as approximations derived from Herterich and Hasselmann (1980) scaled to deep water S_{nl} (Resio and Perrie 1991) will be implemented in 3rd generation wave modeling technologies leading to an improved Discrete Interaction Approximation (DIA) presently used in operational wave models (Komen et al 1994). Data obtained from SHOWEX will be used for the source term balance adjusting the formulations for S_{in}, S_{ds}, and S_{wb} derived from the data.

WORK COMPLETED

Pursuing a replacement for the DIA in existing Navy operational wave modeling technologies has focused on reducing the computational load required for the exact Webb-Resio-Tracy (Resio et al al (accepted for publication, *JGR*) or the WRT method. Three methods have been pursued. The first method conditionally relaxes the computational space decreasing the frequency/directional resolutions. The second method takes advantage of new High Performance Computing architectures, and tools for implementation on scalable platforms. The third method focuses on the synthesis of a large number of exact WRT simulations for various input spectra to determine if a statistically coherent form of S_{nl} can be described in frequency and direction space using a large population of measured directional spectra.

RESULTS

The most computational intensive portion of all exact Boltzmann integral solution methods for nonlinear four-wave interactions is in the calculation of the coupling coefficients. Reducing the domain for these calculations, and/or reducing the resolution in the integral space would effectively reduce the computational burden. This reduction will impact S_{nl} accuracy. The goal is to reproduce temporal and spatial growth characteristics without appreciably tuning the atmospheric (S_{in}) input, or high frequency dissipation (S_{ds}) source functions. Through analysis we have found the WRT method is extremely sensitive to the frequency/directional resolution for the spectral shape and wind scenarios. Interactions in the neighborhood of the spectral peak are strong, and to preserve the "+/-/+" signature of S_{nl} a high-resolution frequency domain is required. A slight reduction in the frequency resolution (despite weighting heavily around the spectral peak) will promote multiple interactions, and eventually cause temporal growth to diverge from well-established growth rate expressions shown in Figure 1). A reduction from 45 to 33 frequency bands with a weight factor of 1.05 versus 1.1 (e.g. $f(n+1)=\lambda*f(n)$ where λ is the weighting factor and n is the frequency band) will result in substantial differences in the growth characteristics for even a simple test. Navy wave forecasting models nominally use 25 frequency bands with a λ of 1.1. Based on this analysis, the errors in temporal growth rates would be even greater than that found in Figure 1. In the context of these tests newly developed computational tools permitting parallelization of the WRT solution method were used. These tools decreased run times by an order of magnitude, however scaling the problem to present navy operational needs will require a speed up of three orders of magnitude. Work continues on alternative integration methods, interaction domain specification.

The third focused effort involves the synthesis of many runs using the WRT method for a large population of measured directional wave spectra. Using multivariate data analysis techniques (canonical correlation) a functional relationship between the input spectra and the resulting S_{nl} can be generated. The canonical correlation is the maximum correlation between linear functions of the two vector variables (namely the input spectrum and the nonlinear wave-wave interaction solution for that spectrum). One can think of this as a multidimensional mapping that maximizes the correlation between the input function and its result. The relationship between the input spectra and S_{nl} are apparent. There is a strong positive transfer of energy around the spectral peak, a negative lobe in the rear face, followed by a positive lobe at the higher frequencies. A persistent positive lobe near the tail
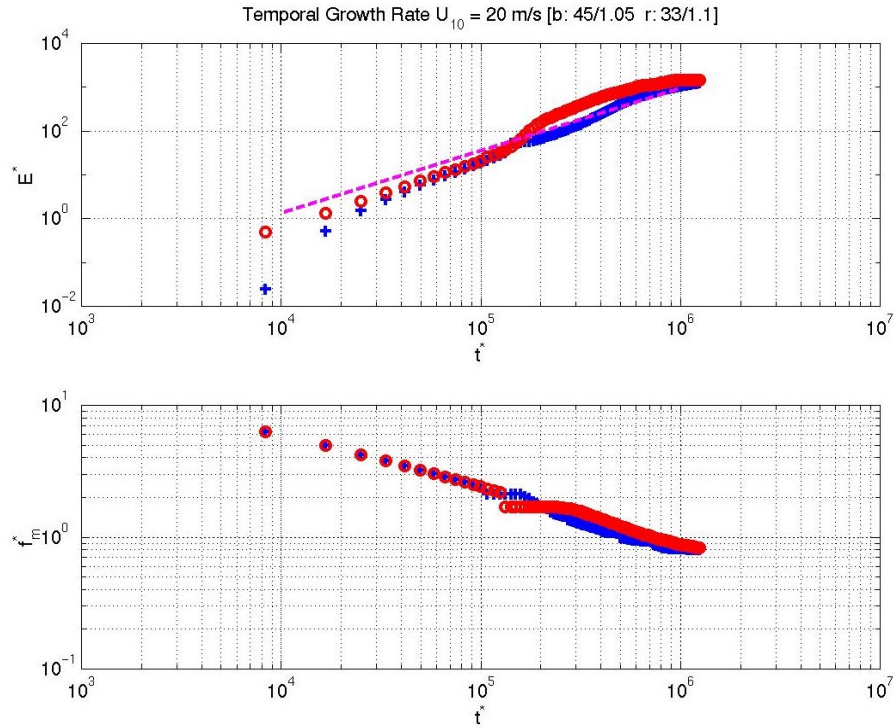
Figure 1. Temporal growth rate using WRT exact solution with S_{in}, and S_{ds} compared to growth rate of Resio and Perrie 1989.

is an artifact caused by a discontinuity in the input spectrum. Rectification of this is underway. The S_{nl} results also oscillate in the rear face region caused by small-scale energy lobes in the input spectrum. These results are real, and will redistribute the energy a rate two orders of magnitude faster than the source term time steps presently used in operational wave forecast models. This technique will be expanded into the directional domain, initially with the peak direction at each frequency band, followed by the full directional distribution.

IMPACT

One views the continental shelf as an environment that significantly alters the deep-water directional wave spectrum. The source/sink terms impact their control over changes in the directional spectrum while bathymetric effects attempt to steer the energy dictated by local water depth gradients. What has been found thus far is that the arbitrary depth WRT S_{nl} is extremely sensitive to the frequency banding that may preclude inclusion of a less accurate, yet more computational efficient routine. The canonical technique shows promise in reproducing the exact solution, and be as computational efficient as the DIA. The net gains in the correct estimation of S_{nl} as well as the basis to make significant strides in replacing the DIA with a far more accurate approximation is now within reach.
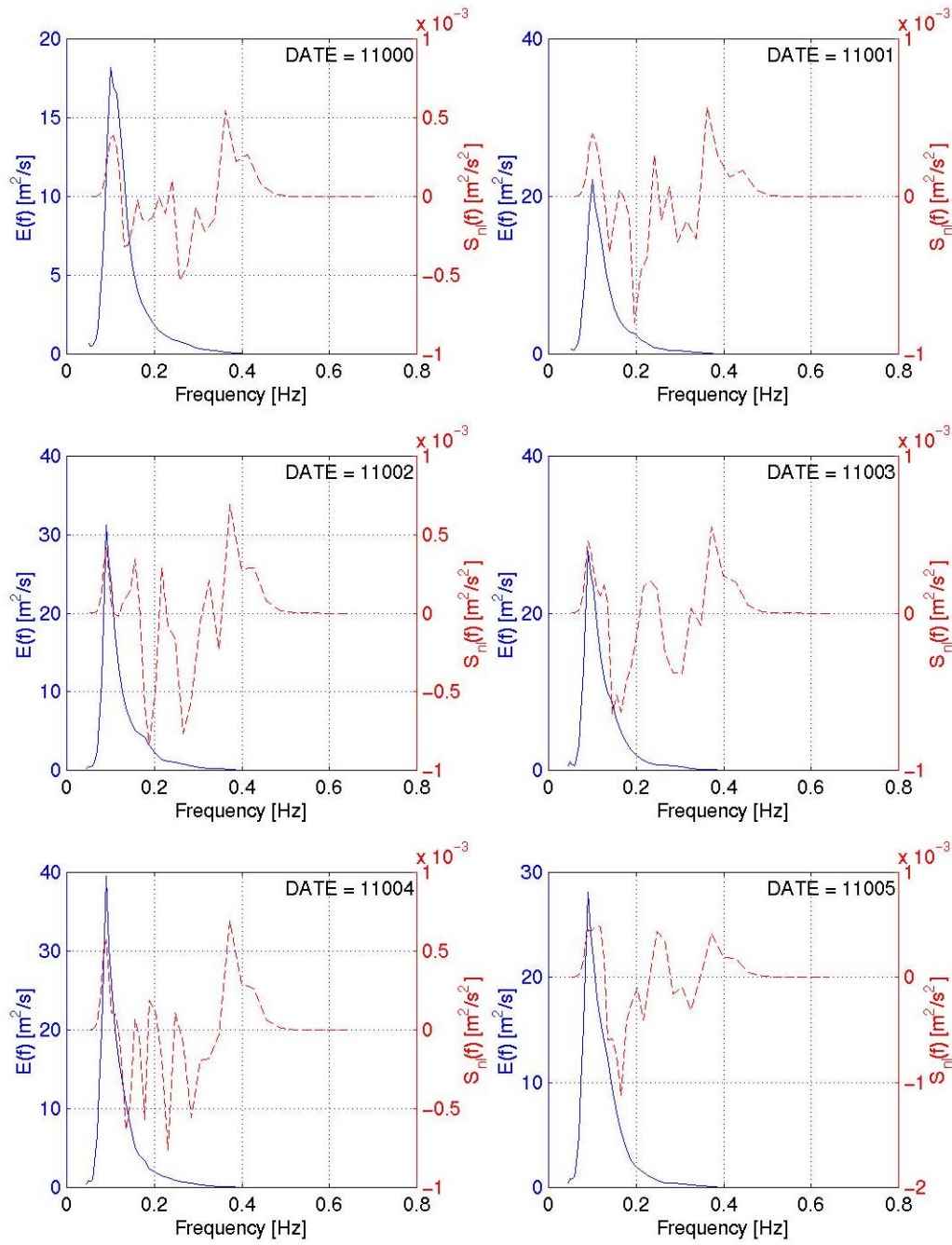
Figure 2. Results of the WRT S_{nl} exact calculations using measured directional wave spectra during a strong northeaster

TRANSITIONS

The results derived from this study will be further developed in a transect model containing the complete set of source terms as well as the effects due to changing water depths. This model will be used to calculate near real time source term balances during SHOWEX. The WRT method will be incorporated in the architecture for research purposes and evaluated for deep and arbitrary depths. Ultimately, the results from these projects will yield a newly formulated approximation to S_{nl} to be ingested in Naval Operational Wave Forecasting Systems for better approximations of wave conditions over the continental shelf.

RELATED PROJECTS

Listed below are various projects that are directly related to the SHOWEX and the AWPP.

1. Headquarters, U.S. Army Corps of Engineers: Modeling the Evolution of Directional Wave Spectra in Arbitrary Water Depths. Development, investigation, validation of modeling technologies and transition to the U.S. Army Corps of Engineers district, division offices and in-house Coastal and Hydraulics Laboratory staff for use in the estimation of wave condition in the nearshore domain.

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Resio, D.T., Rasmussen, J.H., Tracy, B.A., and Vincent, C.L., (accepted for publication *J. Geophys. Res.*). The finite-depth equilibrium range in wave spectra related to nonlinear wave-wave interactions."

PUBLICATIONS

Resio, D.T., Rasmussen, J.H., Tracy, B.A., and Vincent, C.L, (accepted for publication *J. Geophys. Res.*). The finite-depth equilibrium range in wave spectra related to nonlinear wave-wave interactions.